ASSESSMENT ON FATIGUE BEHAVIOUR OF AL7475 T7351 SUBJECTED TO NATURAL CORROSION, ACCELERATED CORROSION AND ARTIFICIAL DAMAGES

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01 Background

Corrosion Damage

Corrosion is one of the most important threats which needs to be considered as a source of accidental damage for the fatigue tolerance evaluation of susceptible metallic parts. Corrosion adversely impacts the structural integrity of aircraft, reducing the fatigue strength up to a level which may result in catastrophic failure, if not mitigated through a suitable inspection program involving the evaluation of its effect on the fatigue strength.

Research Aim

In the context of damage tolerance assessment, the activity aims to correlate the fatigue material behaviour in the presence of a corrosion pit, either from natural and accelerated corrosion, with results from artificial defects made by Electrical Discharge Machining (EDM).

Approach and Methods

The analysis is focused on the threshold to propagation of small cracks emanating from corrosion pits and EDM notch. The crack growth threshold and the fatigue endurance limit are combined through the Kitagawa-Takahashi diagram, defining the area of non-propagating cracks. For small defects, in place of the crack length, the √area parameter model proposed by Murakami and Endo is adopted. The √area is defined as the square root of the defect area projected onto a plane perpendicular to the maximum tensile stress.

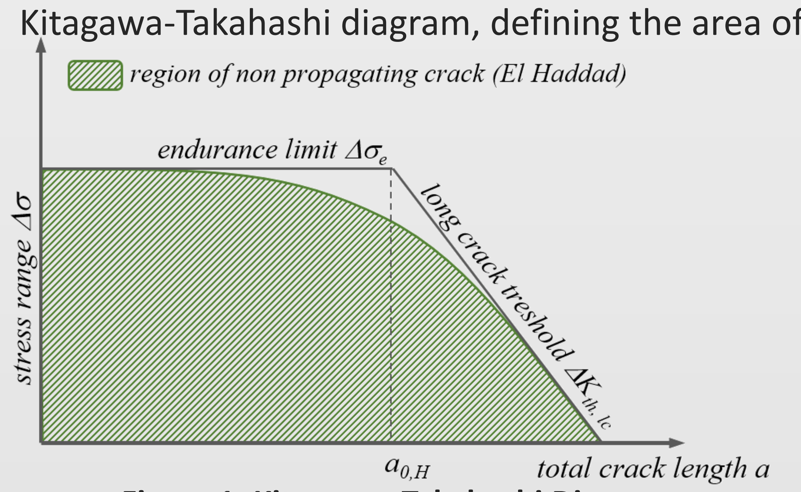

Figure 1: Kitagawa–Takahashi Diagram

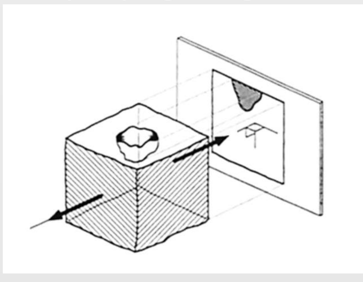

Figure 2: Definition of Varea Parameter

Experimental activities have been performed on Aluminium Alloy 7475 T7351 in alternate bending, with a target defect √area of 0.445 mm, equivalent to a semi-circular flaw of 0.35 mm radius.

02 Artificial Defects

EDM Electrical Discharge Machining (EDM)

EDM technique guarantees high repeatability minimizing the residual stresses at the tip of the flaws; inflicted defects have a semi-circular penny shape (Figure 3); the obtained √areas are shown in Figure 4.

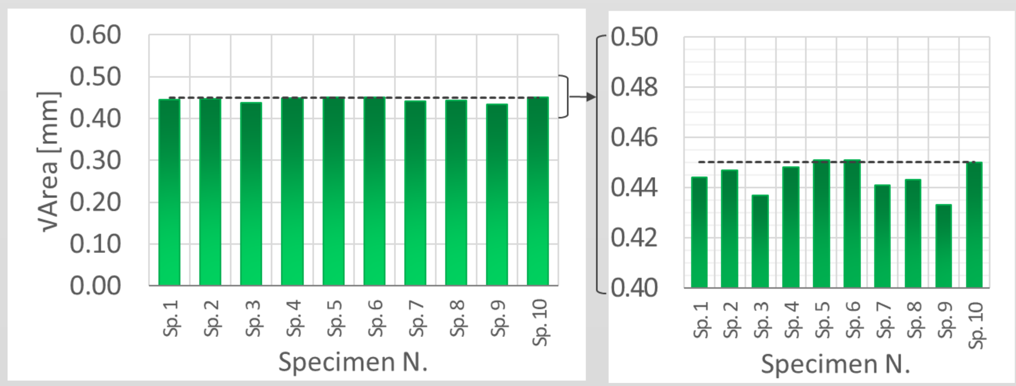

Figure 4: EDM Notch Varea vs Target (dotted line: √area=445mm)

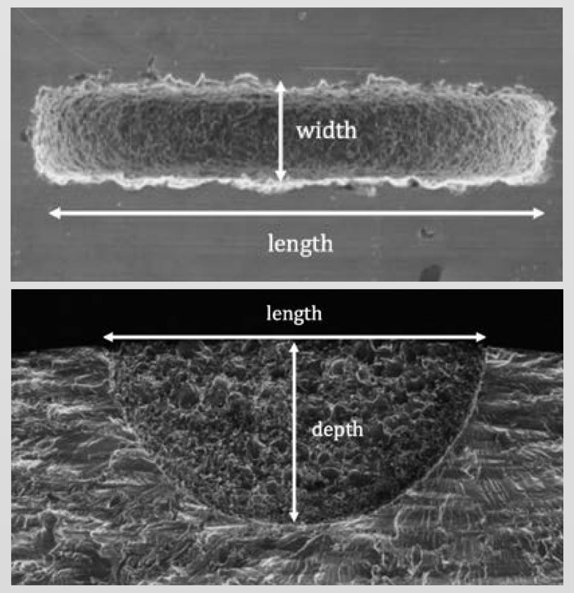

Figure 3: EDM Notch - Longitudinal and Transverse View

MH Micro Holes

Natural corrosion pits are significantly smaller and thus not directly comparable with the present target damage size; for this reason, Kitagawa plots resulting from a comprehensive material characterization previously carried out with the defect type in Figure 5, have been included into the results analysis.

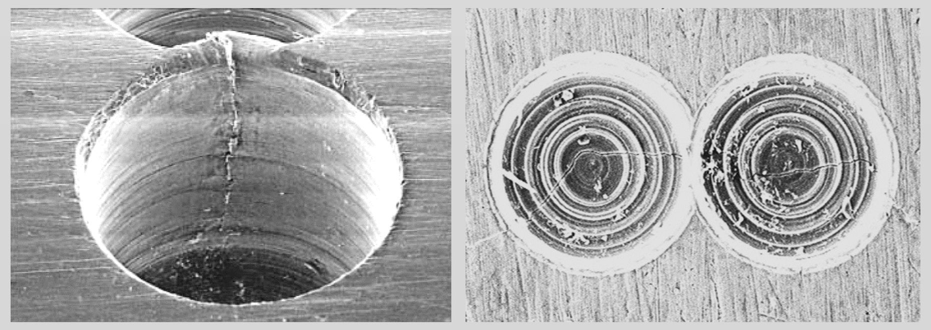

Figure 5: Crack from Micro Holes

03 Protection

Specimen Preparation

In order to obtain a localized corrosion attack, specimen surfaces have been protected applying a transparent water-resistant polyethylene (PE) tape with a 1.4mm diameter hole and a black self-amalgamating tape, or electrical insulating tape for salt fog tests (ref. Fig. 6).

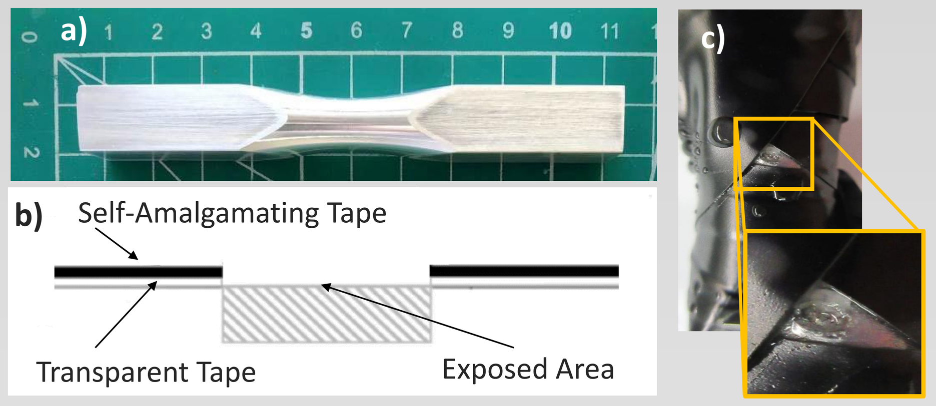

Figure 6: a) Specimen Before Shielding b) Protective Layers c) Area Exposure Details

04 Natural Corrosion

NUA Natural Exposure to Urban Atmosphere

Exposure Environment: open-air exposed in Urban Environment, on the roof of the Department of Chemistry, in Milan

Exposure Time: 1 Year

Corrosion Results: no corrosion attacks of significant depth.

NMA Natural Exposure to Marine Atmosphere

Exposure Environment: open-air, in marine environment at CNR laboratory plant in Bonassola (La Spezia, Italy); the exposure point is 6m above and 15m far from the sea, E-SE oriented

Exposure Time: 1 Year

Corrosion Results: several small corrosion attacks were detected on all the specimens. The actual corrosion pit dimensions were measured on failed specimens, resulting in an average √area of 0.082 mm, equivalent to a semi-circular flaw of 0.065 mm radius (ref. Fig. 7 and Fig. 8).

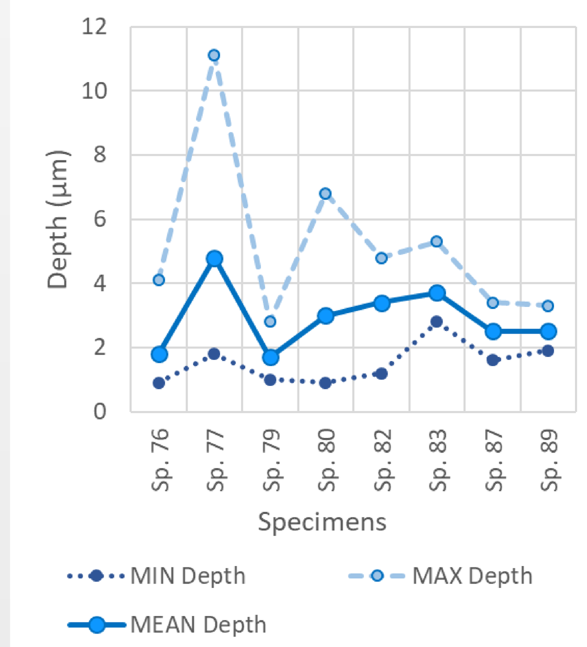

Figure 7: Natural Marine Corrosion Pit Depth

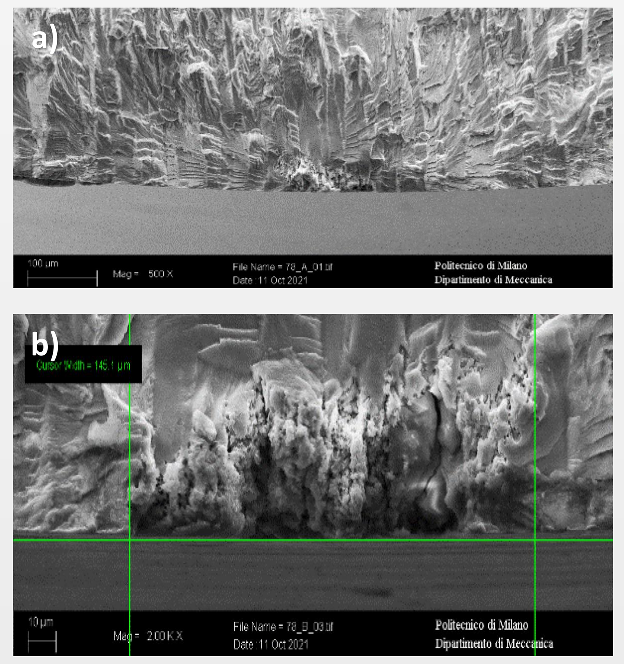

Figure 8: a) SEM view of a Natural Marine Corrosion Pit, b) Pit Detail

05 Accelerated Corrosion

GC Electrochemical Attack - Galvanostatic Corrosion

Exposure Environment: specimens are connected to the positive a pole of a galvanostat; a mixed-metal oxide covered titanium mesh (MMO-Ti), used as counter-electrode, is connected to the negative pole. The aluminium specimen, immersed in a corrosion cell containing distilled water and 5 g/L NaCl, works as anode and its corrosion rate has been controlled by the application of an external constant current.

Exposure Time: defined based on mass loss and penetration rate through the Faraday's law (approx. 10 hours)

Corrosion Results: galvanostatic corrosion proved to be a reliable method to obtain a corrosion pit of the target dimension (ref. Fig. 9 and Fig. 10).

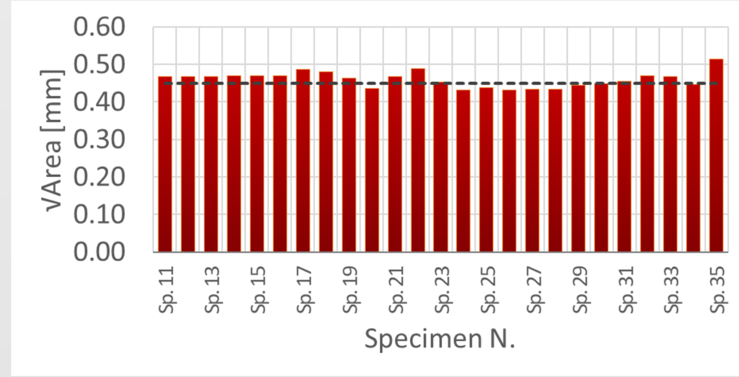

Figure 9: Galvanostatic Corrosion Pit Vs Target size (dotted line)

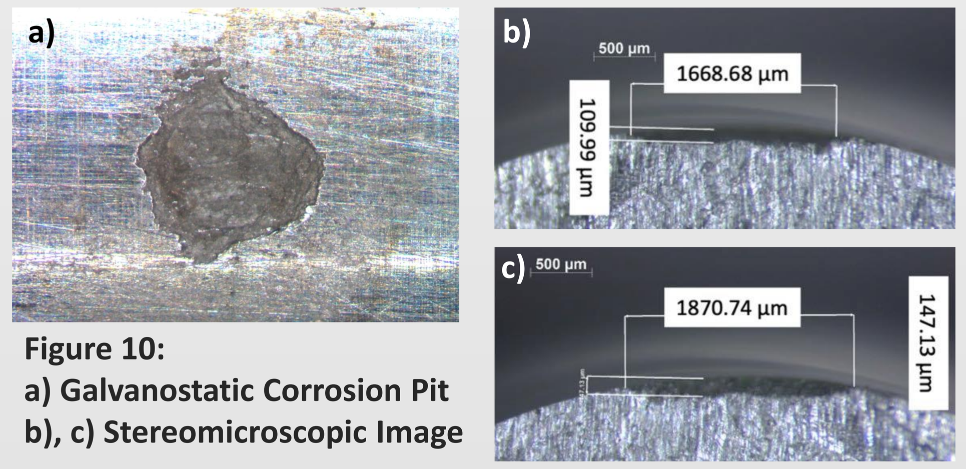

Figure 10:
a) Galvanostatic Corrosion Pit
b), c) Stereomicroscopic Image

SSF Salt Spray Fog Chamber

Exposure Environment: salt fog chamber, exposed to a solution of 5% sodium chloride (NaCl) with a temperature in the range 35 ± 2 °C

Exposure Time: 2 months, periodically visually examined and then re-inserted into the salt spray chamber.

Corrosion Results: salt spray corrosion has been the less controllable process, however a selection of specimens with pit dimensions comparable with target EDM flaws were obtained (ref. Fig. 11 and Fig. 12).

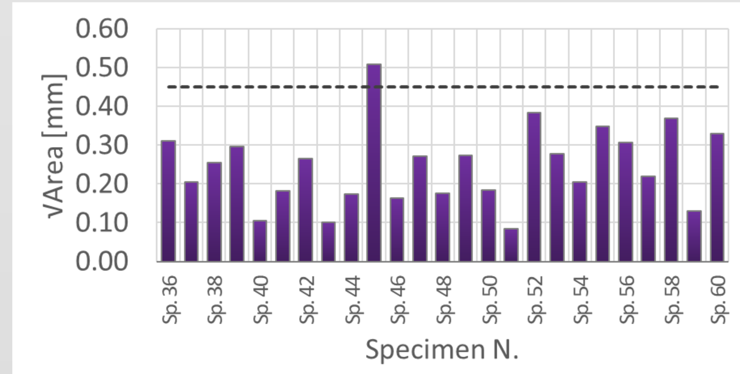

Figure 11: Salt Fog Corrosion Pit Vs Target size (dotted line)

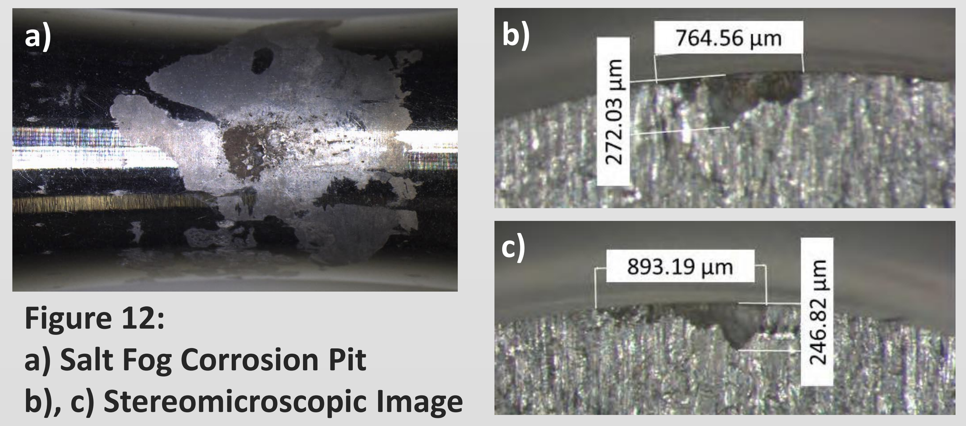

Figure 12:
a) Salt Fog Corrosion Pit
b), c) Stereomicroscopic Image

06 Analysis & Results

Fatigue Tests and Specimen Selection

Fatigue tests have been performed to define the fatigue endurance limit for each type of defect at a constant stress ratio of R=0.1, selecting the specimens in order to have a nominal value of √area as close as possible to the target value of 0.445 mm.

Analysis Method and Results

The fatigue limit is obtained adopting the Hodge-Rosenblatt simplified stair case statistical method; the results for the four different tested damage types shown in Figure 13 confirm that artificial corrosion and EDM defects, have the same fatigue strength.

Natural corrosion pits are significantly smaller and thus not directly comparable with EDM flaws or artificial corrosion pits; for this reason they are compared, in terms of El-Haddad model, with the Kitagawa plot obtained during a comprehensive material characterization carried out in the past on the same material with Micro Holes defects, and traced onto Figure 14. The results confirms also for this case the equivalence, in terms of threshold to crack propagation, between the fatigue behaviour of the defects generated by natural corrosion and those obtained with artificial mechanical processes.

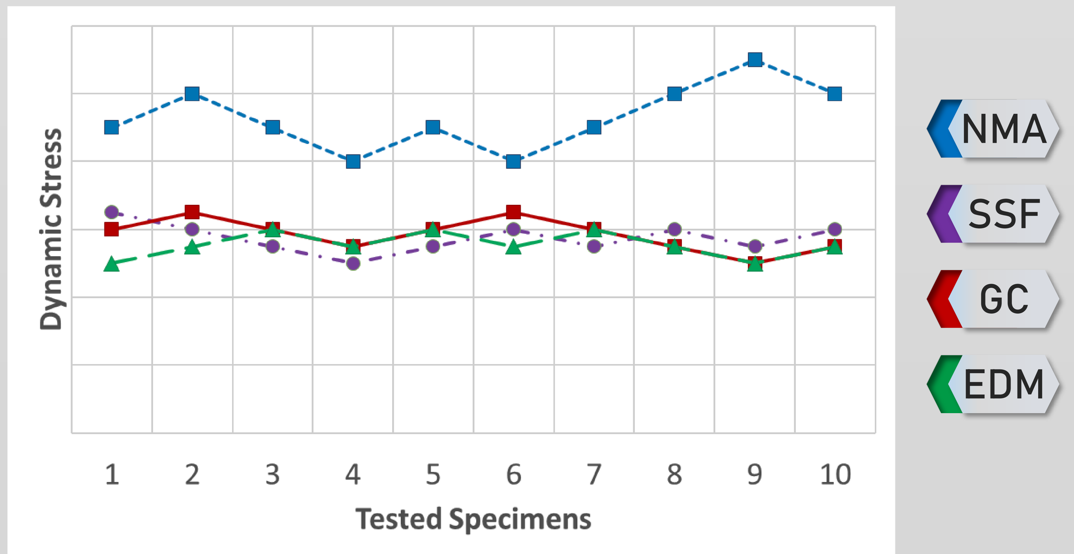

Figure 13: Comparison of Stair Case Sequences

07 Conclusion

Type of Damages: results show a strong correlation among the threshold to propagation from accelerated corrosion, natural corrosion and the artificial flaws.

Kitagawa Diagram and Varea Model: experimental data confirm the applicability of Kitagawa diagrams derived from inflicted artificial defects to describe the no crack growth behaviour in presence of corrosion pits of equivalent √area.

The fatigue material behaviour in presence of a corrosion pit, either from natural or accelerated process, is equivalent to results obtained with artificial defects inflicted by Electrical Discharge Machining of the same √area. Fatigue behaviour defined from natural corrosion defects, that resulted in a smaller value of √area, are also well in accordance with the El-Haddad model of the Al7475 T7351, traced from a previous comprehensive material characterization with cracks generated from micro-holes.

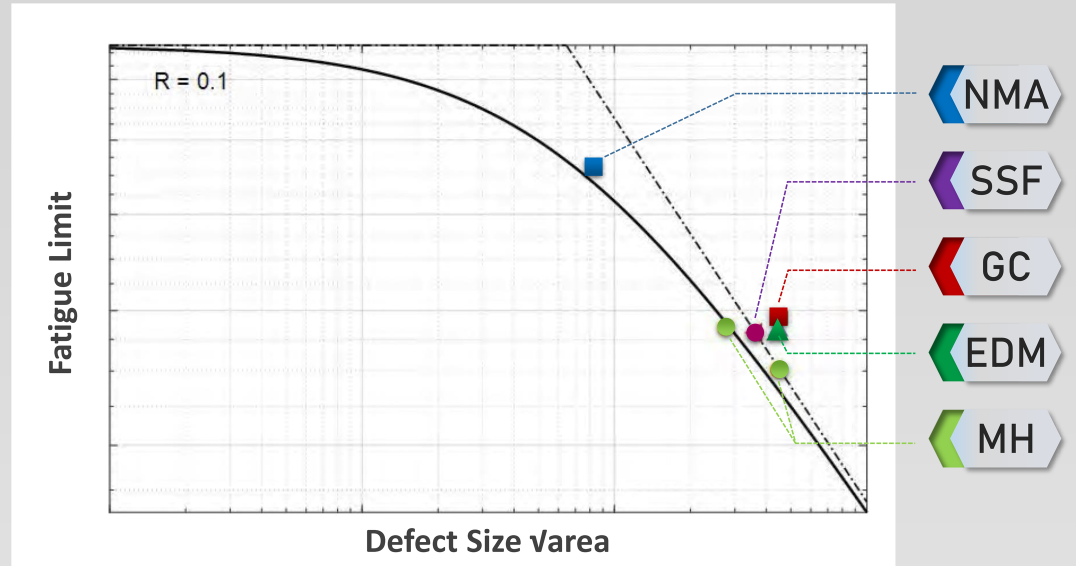

Figure 14: El-Haddad Model (R=0.1)